National Bureau of Standards

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X-Ray Measurement of Strain in Metal

It is possible, by means of X-ray diffraction, to measure the interatomic spacing of crystals. Because a crystal deforms under the influence of an applied stress, with a resultant change in the interatomic spacing, X-ray diffraction can be utilized to determine the magnitude of strain in the crystal. Such a method of measuring strain offers many advantages, but several unresolved difficulties have limited its application, though the technique has been under study for the past 25 years. Comprehensive investigations by the Metallurgy Division of the National Bureau of Standards in the field of X-ray strain measurements have been directed toward improving the sensitivity and precision of this method of determining strain in metals.[1] The Bureau's special interest lies in the possible importance of the method in detecting fatigue damage in metals before an actual fracture occurs.

Deformation of metals can be of two kinds, elastic and plastic. Elastic deformation is the result of a change in interatomic spacing, whereas in plastic deformation slipping of the atomic planes takes place without change in the dimensions of the crystal lattice. Because of this difference, the strain measured by X-ray diffraction is limited to the elastic portion and is not affected by plastic deformation. For some purposes this is a major advantage as compared to those methods that measure only the total strain. Other advantages are (1) The length over which the strain is measured can be made very small; (2) the strain can be determined without the necessity of a measurement on the unstrained metal; (3) the strain is measured in a very thin surface layer. These advantages make the method particularly suited for applications such as the determination of internal stresses in metals.

As opposed to the advantages of the X-ray method of measuring strain, there are several disadvantages, the most serious of which is the lack of sensitivity. The determination of strain involves measuring the change of diameter of the diffraction ring from the specimen. In the case of metals this ring is inherently quite diffuse due to imperfections in the metal crystal. With annealed metals the width of the ring is about the same magnitude as the maximum diameter change expected from elastic strain. For cold-worked metals the ring becomes much more diffuse, and it is difficult to detect any change due to elastic strain.

Although improved X-ray strain measurements have resulted from the Bureau's investigation, the work was initiated primarily to apply the X-ray stress-measurement technique to detection of fatigue damage in metals. Fatigue is the term used to denote the progressive fracture of metals under the action of fluctuating stress. The magnitude of the fluctuating stress that will eventually cause failure is much smaller than that required to fracture the metal under static conditions, and as a result fatigue is a primary cause of failure in machine elements. The course of a fatigue fracture can be

[1] For further technical details, see Calibration of X-ray measurement of strain, John A. Bennett and Herbert C. Vacher, J. Research NBS **40**, 285 (1948) RP1874.

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divided into two stages: (1) The metal undergoes some sort of deterioration or damage that finally results in the formation of a very small crack; and (2) the crack grows until the member is weakened to such an extent that it fractures suddenly. At the present time no reliable method is known for the evaluation of the damage that takes place during the first stage except through a fatigue test. It would be extremely valuable if some means were available for measuring this damage by nondestructive means.

In 1941, Glocker, in Germany, reported the results of X-ray stress measurements made on fatigue specimens, by means of which he claimed to be able to detect fatigue damage. The method involved the measurement of surface stress in the specimen under static load after various amounts of fatigue stressing. He found that after the specimen had been damaged by fatigue stressing, the stress in the extreme surface layers was not as large as it would be if the material were homogeneous. Because of the apparent significance of these results, it seemed desirable to pursue further this line of investigation at the Bureau.

It was immediately evident that the primary requirement was to obtain better precision of stress determination than is possible with the methods commonly used. In the method devised at the Bureau, the film is placed at right angles to the incident X-ray beam so that it intersects a diffracted beam at an angle that depends on the spacing of the reflecting planes, according to the Bragg equation,

$$n\,\lambda = 2d \sin\theta.$$

In this equation n is the order of the reflection, λ is the

In apparatus assembled at the Bureau for X-ray measurement of strain in metals, the beam emerges through a pinhole at the center of the circular film holder (center). It is then diffracted by the crystals of the metal specimen under tensile stress (in front of film holder) back to the film in the holder.

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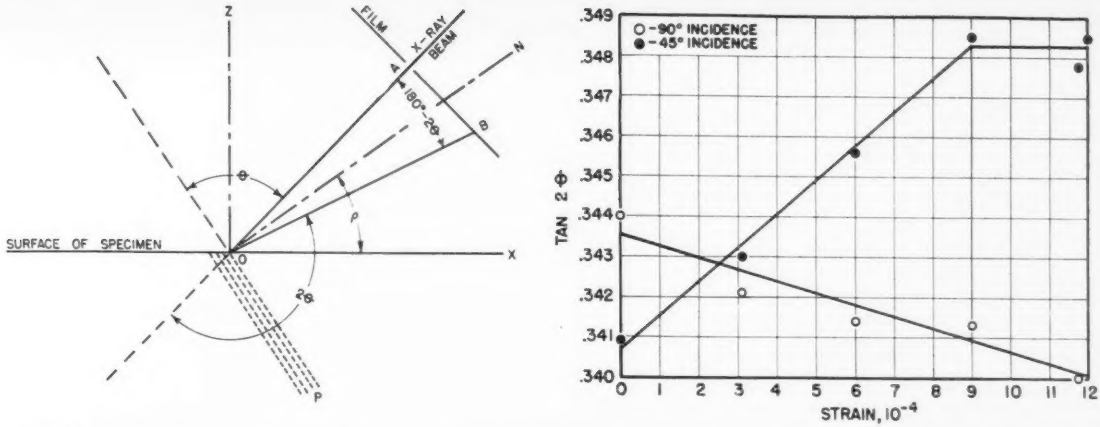
wavelength of the X-rays, d is the interplanar spacing, and θ is the diffraction angle. When d is changed by the application of stress to the specimen, the strain in the direction of the normal to the reflecting planes is measured by the change in θ. As X-rays can be diffracted in any direction making an angle of $180^\circ - 2\,\theta$ with the incident beam, the diffracted beam forms a cone that intersects the film in a circle. The diffraction angle is computed from the specimen-to-film distance and the radius of the diffraction ring. It is usual practice to measure the radius at one or two points with a vernier scale.

The primary factor that limits the precision of the X-ray measurement of stress is the diffuseness of the diffraction ring, which makes it impossible to obtain exact values for the ring radius. As there did not appear to be any experimental method that would significantly improve the accuracy of a single measurement, it was decided to increase the precision of the stress determination by making a number of measurements of ring radius. For each stress condition, therefore, 2 diffraction patterns were taken at different angles of incidence, and 12 measurements of ring radius (at 30° intervals around the ring) were made on each pattern by using a recording microphotometer.

Because the diffraction ring of a stressed specimen is not exactly circular, special methods of handling the data were developed to give a single value representative of the 12 radius measurements. These methods, which



Methods developed at the Bureau for measuring strain in metals by means of X-rays have resulted in improved accuracy and sensitivity. The principles of the procedure are illustrated by the schematic diagram (left). Measurement of diffraction rings recorded on the X-ray film permits determination of strain in the specimen. Plotting the data obtained by exposing a flat steel specimen under tensile stress to X-radiation, against surface strain measured with wire strain gages, gives a calibration curve (right) for the method.

were used in the cases where averaging the measurements would have resulted in a loss of sensitivity, are valid only for uniaxial stress in the surface of the specimen.

In order to calibrate the method, tests were made on a flat steel specimen loaded in bending to produce a tensile stress in the surface under examination. The actual strain in the surface of the specimen was measured with wire strain gages placed above and below the spot that was irradiated with X-rays. The results may be shown by means of a graph, on which the values obtained from measurement of the diffraction ring are plotted against the surface strain (see calibration curve). Each of the points represents data from one diffraction pattern. Patterns taken with the incident beam normal to the surface give one curve, and those with 45° incidence give another. The direction of change of θ is different in the two cases, because the lattice contracts in directions at right angles to the applied stress.

A significant fact is revealed by the curve for 45° incidence, which flattens out at a strain value of about 9×10^{-4}, indicating that plastic deformation occurred when the strain was greater than this value. However, the 90° curve shows no flattening up to the maximum applied strain. From this it appears that plastic deformation in one direction in a crystal does not affect the atomic spacing or elastic properties in other directions where the strain is not great enough to cause slip. Such results suggest that the measurement of lattice strain by means of X-rays might provide a powerful tool for the investigation of the mechanism of plastic deformation.

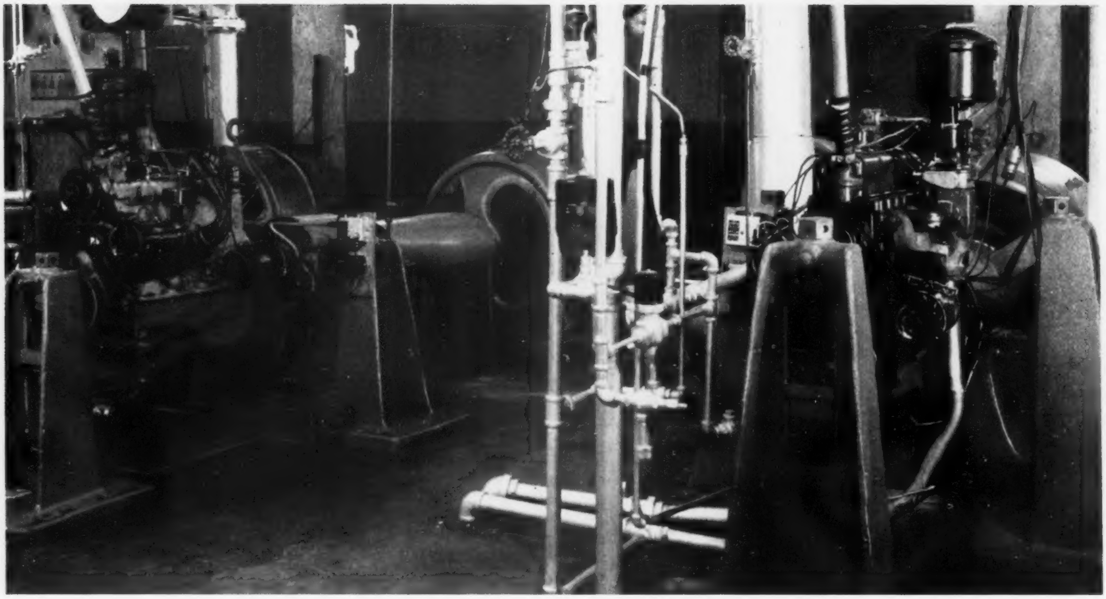
In order to obtain a single value representative of the lattice strain, the difference between the values at 90° and 45° was used. The relationship between this difference and the measured surface strain was found to be linear, the maximum deviation of any point from a linear relationship corresponding to about 1,000 lb/in.² stress.

Laboratory for Study of Cylinder Wear

A new laboratory for the study of automotive engine performance has been installed at the National Bureau of Standards under the direction of A. R. Pierce. Equipped with completely automatic controls, this laboratory offers a means of closely simulating actual operating conditions in such a way that tests can be reliably duplicated. Although designed primarily for investigations of cylinder wear, the new equipment may also be used in studying the effects of various types of fuels and lubricating oils on pistons, piston rings, bearings, and carburetors. A problem under investigation at the present time is the determination of the amount of sulfur that can be tolerated in gasolines without appreciably increasing wear.

Cylinder wear is an important factor limiting the useful life of automotive engines. In general, reliable data on the process can be obtained only by actual operation of a test engine under conditions of frequent starting, stopping, accelerating, and cooling, such as occur in normal driving. Road testing has not given reliable results in this work because it is impossible to control properly all conditions of operation. In connection with the Bureau's study of cylinder wear, it was therefore necessary to develop a laboratory arrangement for testing automotive engines under conditions such that any run could be exactly duplicated.

The automatic test equipment utilizes a battery of five automotive engines from three popular makes of



A set of five automotive engines, together with the necessary controls, makes up the Bureau's new automatically controlled laboratory for research on cylinder wear. These engines are operated through a test cycle that closely simulates actual driving conditions. Electric dynamometers connected to the engines provide uniform load. The test cycle consists of cold starting, and warm-up, speed-up, idling, stopping, and cooling periods. A complete cycle requires 30 minutes. Individual control panels (left) allow manual operation for adjustment or repair.

automobiles. Each engine is complete except for fans, radiators, and mufflers, and is coupled to a "dynamometer"—an electric generator that provides a uniform load. By varying the electrical output of the dynamometer, and by regulating the amount of throttle opening, any speed or power within the range of the engine may be obtained. The extent of cylinder wear is determined by use of the McKee Wear Gage,[2] which employs a sensitive indentation method developed at the Bureau for investigations of the wear of walls and pistons of internal combustion engines.

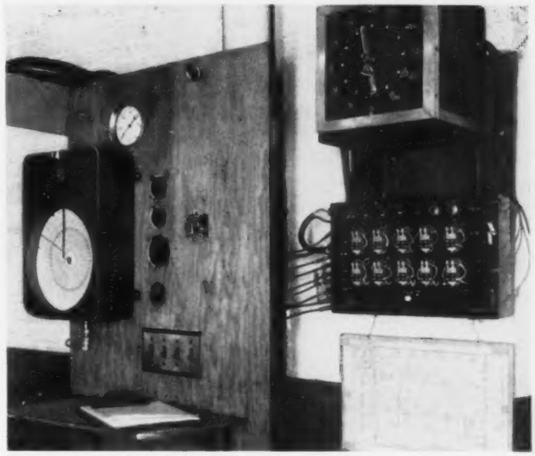
To obtain data that are valid for actual service, the engines, under the control of a master clock, are put through an operating cycle that provides conditions corresponding to cold starting, warm-up, speed-up, idling, stopping, and cooling. The $\frac{1}{2}$-hour cycle that is used begins with cold starting, after which the engines are first idled for $1\frac{1}{2}$ minutes at 500 rpm, then accelerated for $3\frac{1}{2}$ minutes at a speed equivalent to 40 miles per hour on the road and a horsepower output equal to "road load". The idle and speed-up periods are repeated three times. At the end of the fourth speed-up period, the engines are stopped, and during the remaining 10 minutes of the cycle they are artificially cooled to the original starting temperature in preparation for another cold start. The cycle can be repeated automatically as many times as desired.

A wear test requires many comparison runs. In order that data from successive runs may be comparable, the engine temperature, load, and speed must be accurately controlled. Studies at the Bureau have shown that both starting and running temperatures have an important effect on cylinder wear. For example, it was determined that a greater amount of wear occurs when the engine is operated at temperatures lower than normal. The temperature reached during the cooling period was found to be most important, as wear was doubled when shutdown temperature was dropped 10° F in the region near freezing. Temperature must therefore be carefully regulated in order that results obtained with different fuels may be comparable.

Maintenance of standard conditions also requires proper control of load. If the power output were not constant, the fuel consumption would vary, causing a changing temperature within the combustion chamber. Obviously, speed must also be controlled in wear tests so that each engine may run approximately the same number of revolutions and thus have the same amount of piston travel.

As the engines are not equipped with radiators and fans, proper cooling is obtained during normal operation by means of the engine water pump, which circulates water through the water jacket and into a stand pipe, from which it is returned to the pump. Whenever the temperature of the water exceeds the normal operating temperature, an adjustable thermostat in the pipe line automatically opens a hydraulically operated valve, admitting sufficient tap water to maintain the desired temperature, while the excess passes into the drain.

[2] NBS Technical News Bulletin 31, No. 7 (July 1947).



Simultaneous cyclical operation of the engines is regulated by an electric clock (upper right), which makes contacts at 5-minute intervals, opening and closing circuits to the master relay panel directly below. This in turn operates the circuits that control throttle, cooling system, starter, and stopping mechanism.

At the end of the operating period, tap water is first circulated through each engine and through a coil in the oil pan to remove most of the heat. Further cooling to the cold-starting temperature is then accomplished with water artificially cooled to 50° F. Two cold-water tanks are used for this purpose. One is an ice-water tank containing water a few degrees above freezing. It is equipped with a refrigeration coil, and a circulating pump to prevent excessive icing around the coils. The second tank contains a supply of cold water for circulation. Ice water from the first tank is pumped into this tank as needed to maintain the circulating water at the required temperature. The temperature of the cooling water at all times is shown on a 24-hour recording thermograph.

Automatic Controls

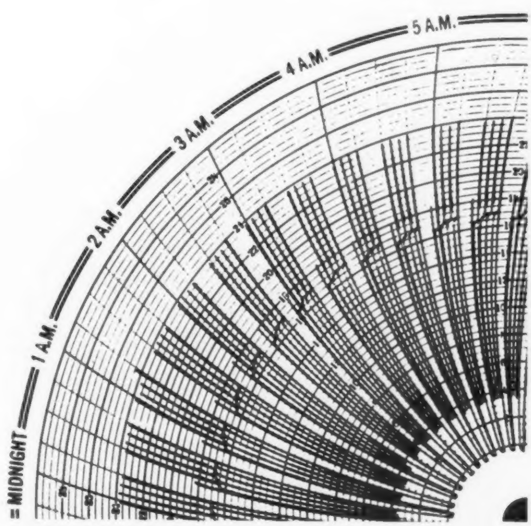
To permit simultaneous cyclical operation of the five test engines, a central panel for automatic timing and control has been installed. The timing device is basically an electric clock that makes contacts at 5-minute intervals, opening and closing circuits to the relay panel at the proper time. The relay panel, in turn, opens, closes, or holds the circuits that operate the throttle, the cooling system, the starter, and the stopping mechanism. Five indicating lights on the panel show what part of the cycle is in progress, thus permitting a ready check on the compliance of the engines with the controls. From this central panel any cycle of operations may be arranged.

In addition, each engine has an individual control panel that contains a recording vacuum gage, an oil-pressure gage, temperature indicators for water and oil, tachometers to show the speed of the engines, and switches for each type of operation. Any engine may thus be cut out of the test cycle and controlled manually during adjustment or repair. This arrangement also permits an engine to be stopped, if necessary, for observation without interfering with the others that are running on the cycle.

In order that corresponding valves for all engines may be operated simultaneously, electric solenoid valves are used. For similar reasons, the throttles are provided with electric solenoids. During the speed run, the throttles are held by a spring against a stop adjusted to a definite setting; during the idling period the solenoid closes the throttle and holds it in this position.

Each engine is equipped with an automatic choke to insure starting after the cooling period, and also with a device that automatically engages the starter at the beginning of the cycle, or whenever the engine may stop running. Intake manifold pressures of each engine are recorded over a 24-hour period by a recording gage. Since the manifold vacuum at a given speed is a function of throttle opening, the operation of the engine is thus charted during the cycle, showing periods of starting, stopping, idling, and acceleration.

Installation of an automatic multiple thermograph to record continuously the temperatures of all engines is planned. When this has been done, tests will proceed without the intervention of an operator. After the engines, the refrigeration, and the clock have been turned on, the central control panel will take over the operation of the test cycle, repeating the cycle until the test is stopped. At the conclusion of each 24-hour period, the temperature chart will show the temperatures of the engines and cooling water, and the charts from the manifold gage will show engine performance.



Automatic recorders provide a complete record of individual engine performance over a 24-hour period. Because the intake manifold pressure is a function of throttle opening, the heavy line that is recorded on the manifold vacuum chart gives an indication of engine speed.

Mechanical Properties of Human Bones

Recent developments in high-speed aircraft have caused flight personnel to be subjected to numerous shocks and impacts in ordinary flight as well as those encountered in accidents. This has made it increasingly important that safety devices be developed for the protection of the human body. It was apparent that in order to establish logical criteria for the design of these devices, a systematic and thorough study of the effects of impacts on the human body was needed. In conjunction with such a study being conducted by the Naval Medical Research Institute, the assistance of the National Bureau of Standards was requested when it was realized that progress in the investigations depended on close cooperation between the engineering and medical professions in order to cope with the mechanical as well as the pathological problems involved.

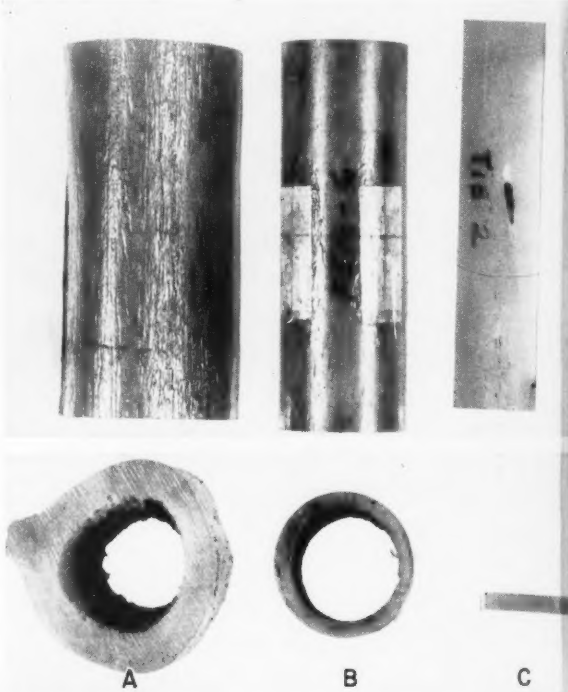
Research with human bones by Frank C. Smith of the Bureau's engineering mechanics laboratory has indicated that ordinary laboratory techniques and instruments may be applied to obtain the much-needed data on the mechanical properties of bone. This knowledge is necessary in predicting body behavior under impact loads as encountered in aircraft crashes, seat-ejection from aircraft, parachute opening, and exposure to blast. Dr. Paul Calabrisi, of the Naval Medical Research Institute and the George Washington Medical School, is collaborating in the study, particularly in connection with the anatomical problems encountered. Preliminary but significant results have been obtained in these investigations.

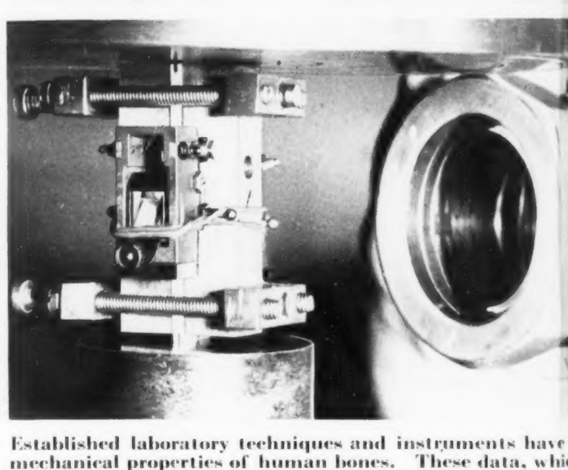
Many instances are known of aircraft and other vehicles crashing to complete destruction where occupants emerge from the wreckage miraculously unhurt. Conversely, a relatively slight blow to certain sensitive portions of the body may have serious and even fatal consequences. It has also been found that naval personnel have been seriously injured from exposure to blast or sudden displacements of ship's structure following the explosion of torpedoes, mines, or the firing of guns.

Because the human skeleton provides support for the body and protection for vital organs, it was decided to begin the study with an investigation of the mechanical properties of human bones and joints. Results are to be used in the design of simplified mechanical models of the human frame that will make possible an estimate of the forces set up in the body during impacts of various types.

There is nothing new in regarding the human body as a mechanical structure. The earliest study of the mechanical properties of bone is believed to have been made by Galileo about 1638, in connection with his classical work on beam mechanics. European investigators began to regard the body frame from a structural viewpoint about 1832, and much work was done during the succeeding century in an attempt to apply theoretical mechanics to the human frame and its components. Another attack on the problem is justified at this time by the spectacular advances, made in recent years, in the technique of measuring strain and other mechanical quantities that have come about largely through research on the behavior of aircraft, both in flight and in the laboratory.

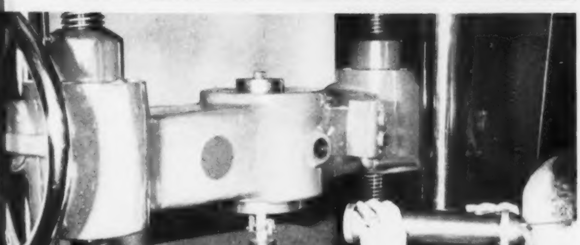
The study was initiated with measurements of the mechanical properties of the structural members of the





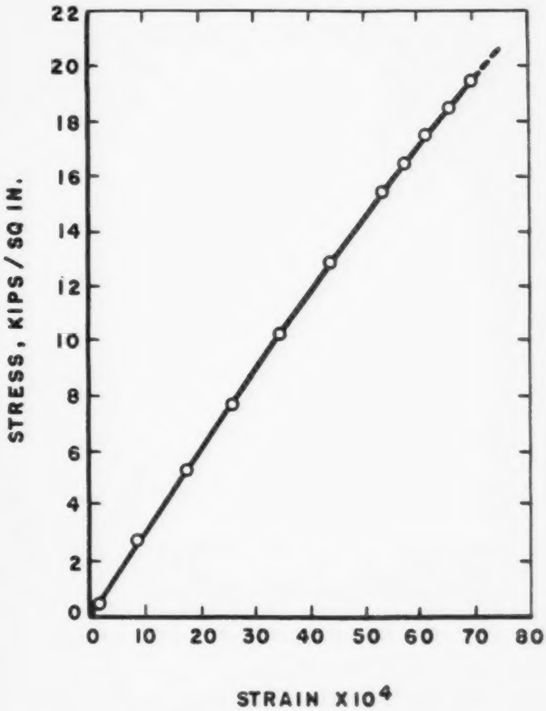
Established laboratory techniques and instruments have ... mechanical properties of human bones. These data, whic... designing safety devices, indicate that bone is an elastic ... For example, it has a compressive strength about one-fo... Three types of specimens (upper left) were subjected to c... gages attached to tubular compression specimens; (lower ... gages attached; (lower right), optical viewing device focuse...

skeleton, beginning with long bones, and was designed to establish average values on a statistical basis. The initial work involved 17 tests on specimens made from bone of the compact type removed from near the middle of the bones of the extremities of humans and monkeys. Fourteen of these tests were made in compression with the direction of the load parallel to the fibers of the bone. One was made in compression with the direction of the load perpendicular to the bone fibers, one in bending, and another under torsion load. Test specimens consisted of sections removed from the bones, and of portions machined into plates and hollow cylinders.



s have [su]ccessfully applied at the Bureau for obtaining data on the a, whic[h] [im]portant in predicting body behavior under impacts and in elastic[ ] material having fairly definite and consistent properties. one-fo[ur]t of cast iron and more than twice that of hickory wood. d to co[mpressi]on, torsion, and bending tests: (upper right), optical strain (lower [le]ft-type specimen supported in special jig, with optical strain focuse[d] [sp]ecimen under test in a standard hydraulic testing machine.

To obtain the mechanical properties of a substance it is necessary to know the compression or extension (strain) of the material for a given load (stress). Given the specimen's average cross section and the load, applied and measured in these investigations with a standard hydraulic-type testing machine, the stress on the specimen may be computed from elementary formulas of strength of materials. The strain in the bone specimens was measured with wire-resistance and Tucker-



Simple straight-line relationships, such as are shown by the stress-strain curve, simplify analysis of the mechanical behavior of the body structure.

man optical strain gages to an estimated accuracy of 0.0000002 in./in. During the investigation, simultaneous strain measurements using both types of gages showed that the electrical strain gage could be used successfully on dry bones but would not function properly on fresh bone because of the inadequate bond between the gage and the oily surface. Earlier data obtained with this gage were corrected accordingly, and all subsequent measurements were made with the Tuckerman optical strain gage.

The tubular compression specimens failed with a sudden snap and with longitudinal cracking, as did the bending and torsion specimens. The restraint of the

special testing jig prevented complete failure of the leaf specimens.

Stress-strain, flexure, and torsion curves plotted from the test data reveal an interesting and significant factor regarding such properties of human bones. The curves are found to lie in approximately straight lines up to failure, thereby simplifying the analysis of the mechanical behavior of the body structure. This means that the load-displacement relations for long bones may be approximated by simple linear equations.

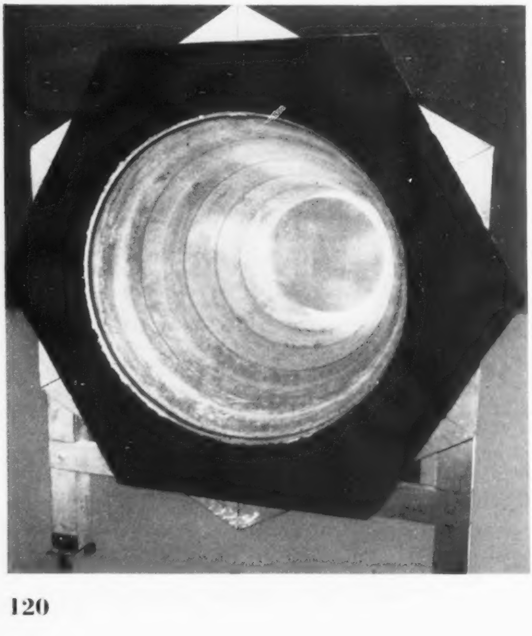
The results of the tests showed the average ultimate strength of the 14 compression specimens to be about 23,000 lb/in. The fifteenth specimen, in which the load was applied at right angles to the bone fibers, had about the same ultimate strength, indicating that the effect of the direction of loading on the bone is small. These strength values are in good agreement with those reported by the early German investigators. The strength of the bone in bending, i. e., extreme fiber stress at failure, was slightly lower than the strength in compression. The computed ultimate shear stress for the torsion to failure was about 15 percent of the compressive strength.

These preliminary data indicate that bone may be considered an elastic, brittle material, having about one-fourth the compressive strength of cast iron and more than twice that of hickory wood. The average Young's modulus of elasticity of the bone, about 2.8×10^6 lb/in.^{2}, is about one-tenth that of steel, or about equal to that of wood. A simple relation was found between the Young's modulus and the specific gravity of the bones tested.

Plans for the next phase of the Bureau's program include compression tests of an entire human knee-joint in the "standing" position. Loads will be applied to the joint in a manner similar to that in which an actual joint is loaded while a person is standing, and measurements made of the consequent deformation of the joint. This test should provide some data on the "spring constant" of the joint, from which a mechanical analogue may be constructed out of springs or rubber. Also underway is a study of the possible correlation between the X-ray absorption properties of bone and its strength and/or stiffness. Such a relationship would be useful in estimating the strength of living bone from X-ray data.

Effect of Screens in Wind-Tunnel Wide-Angle Diffusers

Extensive experimental research under the direction of G. B. Schubauer and W. G. Spangenberg of the Bureau's aerodynamics laboratory has led to a more complete understanding of the effect of damping screens in wind-tunnel wide-angle diffusers.[3] Results have shown that the usual undesirable turbulence in these rapidly expanding ducts can be greatly reduced by suitable location of fine wire screens. Thus, wide-angle diffusers may now be utilized for increasing the cross section of an air stream within a very short length of travel.



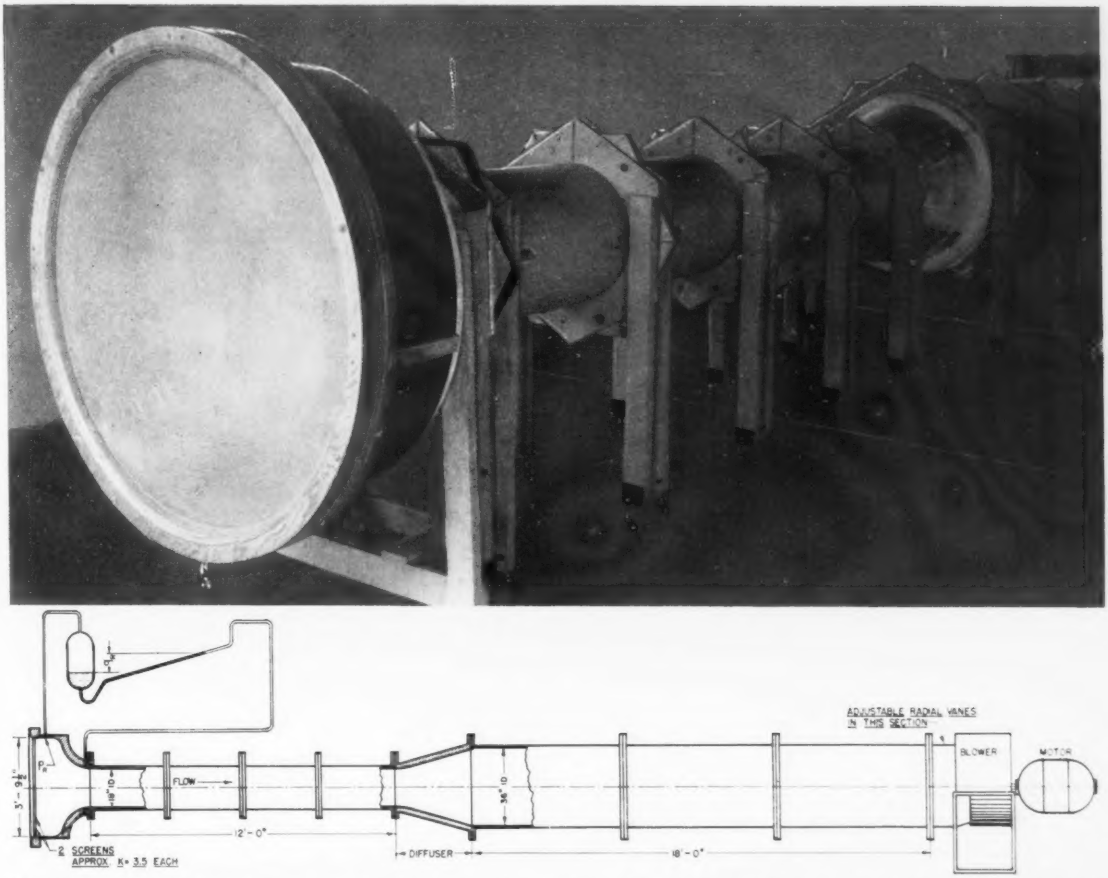
A wind tunnel is designed to simulate, as nearly as possible, the motion of a body through still air by producing a smooth, uniform flow of air past the body. The air stream, drawn through a circuit of ducts by a propeller, is accelerated into the test section—the part of smallest cross-sectional area—through a nozzle or entrance cone. The greater the contraction ratio (ratio of the area of the larger end of the entrance cone to that of the smaller end) the less turbulent is the flow through the test section.

Recent wind-tunnel investigations at the Bureau have shown that damping screens[4] placed across the section upstream of the entrance cone are a very effective means for reducing turbulence in the test section of a tunnel. Whether screens are used or not, however, it is always desirable to have the contraction ratio as large as possible, and this has usually been accomplished in complete-circuit tunnels by making the return circuit of

[3] For further technical details of this work, see NACA Technical Note No. 1610 by G. B. Schubauer and W. G. Spangenberg.

[4] Damping wind-tunnel turbulence, NBS Technical News Bulletin **31**, 1 (1947).

A 28-degree diffuser with five 30-mesh wire screens placed at intervals across the duct was used in a study of the effects of screens in wind-tunnel wide-angle diffusers. Such diffuser-screen combinations increase the cross section of an enclosed air stream smoothly and uniformly.



Proper location of damping screens has been found to reduce the usual turbulence in a wind-tunnel wide-angle diffuser, thus permitting maintenance of smooth, uniform flow as the cross section of the air stream is increased. Air is drawn into the screened entrance cone (left) by a centrifugal fan at the exit. Diffusers of several different included angles, and containing screens at various cross sections, are connected between the two lengths of round duct, and the effects on the flow observed with pitot-static tubes.

long, gradually expanding ducts known as narrow-angle diffusers.

A few years ago, it was observed that the cross section of an air stream could be increased in an unusually short length of travel through a rapidly expanding duct if the larger end of the duct were covered by a screen. This observation by members of the staff of the National Advisory Committee for Aeronautics was very significant, as years of experience had apparently shown that the only way an enclosed stream could be induced to increase its cross section uniformly was by means of a long, gradually expanding duct.

The conventional narrow-angle diffuser is a very long funnel-shaped tube with an included wall angle of about 8°. The term "wide-angle diffuser" is applied to ducts with walls diverging at much greater angles, for example, 30°, or perhaps even 90° in extreme cases. If the transition from a smaller to a larger duct is made through a wide-angle diffuser, flow from the smaller to the larger duct ordinarily becomes very nonuniform, because the air stream will not follow the walls of the diffuser. The flow may also whip from side to side and pulsate violently. These effects are summed up by saying that the diffuser fails to fill.

Because of the importance in engineering applications of this little-understood phenomenon, an investigation of the mechanics of the process was carried out by the National Bureau of Standards with the cooperation of the National Advisory Committee for Aeronautics. A system was set up in which several different wide-angle diffusers could be used to connect a duct 18 inches in diameter to a 36-inch duct, and air was drawn through the system by a centrifugal fan at speeds of about 100 feet per second. By probing along diameters with pitot-static tubes, studies were made of the effects on the flow of fine wire screens (sometimes called wire cloth) placed at various cross sections of the diffusers. Although the screens were all of smaller mesh than ordinary insect screen, the porosity to flow was about the same because of the finer wires.

From detailed analysis of data obtained in a 28° diffuser, it became clear that the characteristic action of a screen is to spread a stream and in this way prevent separation of flow from the diffuser walls. However, the screen must be located sufficiently near to the natural separation point to be fully effective. When it is placed at the large end of the diffuser, it generally does not prevent separation and thus does not produce complete filling. Nevertheless, complete filling may always be attained by the use of several screens at properly chosen cross sections of the diffuser. By giving the diffuser walls a special shape, filling may be obtained with a single screen, but this method offers no advantage over the use of several screens in a duct of simple conical form.

Mathematical relations for efficiency—that is, the ratio of available energy leaving the diffuser to that entering—were found for diffusers containing screens. In general, efficiency is low compared to that of an 8° diffuser without screens. Thus, although screens make it possible to spread a stream over a large cross section in a short distance, they do not permit retention of much of its initial kinetic energy.

Flow measurements were also made on multiple-screen arrangements in a 28° and a 90° diffuser to investigate a possible application of diffuser-screen combinations to the general problem of reduction of turbulence in wind tunnels. When damping screens are used upstream of the entrance cone to decrease turbulence, there is ordinarily an appreciable pressure drop across them because of their resistance to flow. However, if the duct area is increased by a wide-angle diffuser, the pressure drop through the screen may be reduced to negligible proportions, with a significant saving in the power required to drive the tunnel.

Variable-Resistance Spring Transducer

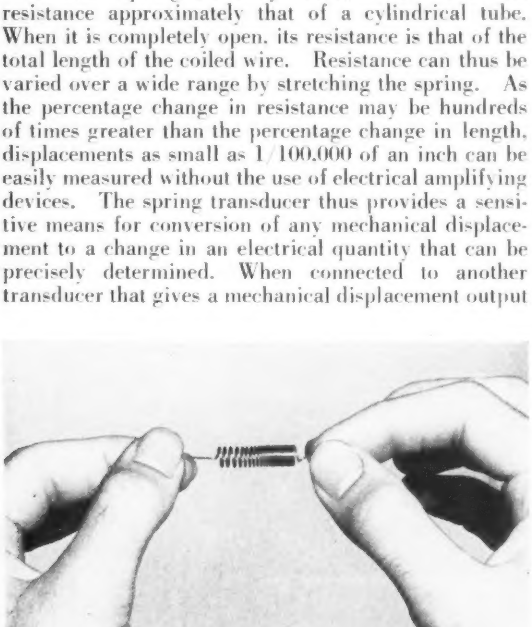
A highly sensitive mechano-electrical transducer, which transforms slight displacements into large changes of resistance, current, or voltage, is being developed by W. A. Wildhack and his associates of the Bureau. The active element of the device is a helical or conical spring wound in such a way that the initial tension varies slightly along its length. Thus, when the ends of the spring are pulled apart, the turns separate one by one rather than simultaneously.

When the spring is entirely closed, it has an electrical resistance approximately that of a cylindrical tube. When it is completely open, its resistance is that of the total length of the coiled wire. Resistance can thus be varied over a wide range by stretching the spring. As the percentage change in resistance may be hundreds of times greater than the percentage change in length, displacements as small as 1/100,000 of an inch can be easily measured without the use of electrical amplifying devices. The spring transducer thus provides a sensitive means for conversion of any mechanical displacement to a change in an electrical quantity that can be precisely determined. When connected to another transducer that gives a mechanical displacement output (a bimetallic strip responding to temperature changes, for example), the combination gives an easily measurable electrical output. This type of use suggests numerous scientific and industrial applications, including strain gages, pressure elements, accelerometers, electric weighing devices, automatic temperature controls, direct-current to alternating-current inverters, and voltage regulators.

The preferable construction for the transducer is a four-arm bridge of which each arm is a variable-resistance spring. An increase in applied tension elongates one pair of springs and shortens the other pair. The resistive unbalance of the bridge, as indicated by a galvanometer, thus gives a measure of the displacement that has occurred. With this arrangement, since the voltage can be nearly reversed through the bridge, the output voltage can be theoretically twice the input voltage.

The variation of the initial tension of the spring along its length may be accomplished in several ways: by conical winding, by varying the angle of feed of the wire on a uniform mandrel, or by varying its tension as it is wound. For greatest sensitivity the variation in initial tension is made quite small. To decrease contact resistance between successive turns of the closed spring, a high average initial tension is built into the spring, and the turns are coated with 0.0001 inch of gold. Thus far, nickel-alloy wire has been mainly used, because of its high resistivity and small change of mechanical properties with temperature.

The new transducer is undergoing further development at the Bureau as part of a project on basic instrumentation for scientific research supported by the Office of Naval Research.



The basic principle of the new NBS mechano-electrical transducer is the progressive separation of the turns of a spring as it stretches. Slight displacements are transformed into larger percentage changes of resistance, current, or voltage. Springs of various sizes and initial tension (lower) are required for different applications.

New Standard Samples of Hydrocarbons

Through a cooperative program of the Bureau and the American Petroleum Institute, 144 compounds are now available as NBS standard samples of hydrocarbons. These standard samples are issued primarily for calibrating analytical instruments and apparatus in the research, development, and analytical laboratories of the petroleum, rubber, chemical, and allied industries. The most recent additions to the series are as follows:

NBS sample number [a]	Compound	Amount of impurity [b]	Volume per unit [c]
		Mole percent	*ml (liquid)*
541-5S	2,2,3-Trimethylhexane	[d](0.30±0.20)	5
544-5S	3,3,4-Trimethylhexane	0.23±0.10	5
554-5S	2,2,4,6,6,-Pentamethylheptane	0.06±0.04	5
270-5S	*cis*-1,3-Dimethylcyclopentane	0.65±0.23	5
530-5S	2-Methyl-1-pentene	0.19±0.09	5
532-5S	4-Methyl-1-pentene	0.18±0.12	5
537-5S	4-Methyl-trans-2-pentene	0.08±0.07	5
547-5S	4,4-Dimethyl-1-pentene	0.15±0.08	5
550-5S	2,3,3-Trimethyl-1-butene	0.06±0.04	5
548-5S	*trans*-4-Octene	0.16±0.11	5
551-5S	1-Nonene	0.24±0.18	5
552-5S	1-Decene	0.11±0.07	5
555-5S	1-Undecene	0.09±0.08	5
513-5S	1,3-Butadiene	[e] (0.08±0.04)	5
549-5S	2-Methyl-1,3-butadiene (Isoprene)	[e] (0.04±0.03)	5
553-5S	1,5-Hexadiene	0.11±0.08	5
557-5S	4-Ethenyl-1-cyclohexene (4-Vinyl-1-cyclohexene).	0.10±0.07	5
556-5S	2,3-Dihydroindene (Indan)	0.06±0.02	5

[a] The designation "-5S" following the sample number indicates a sample of 5 ml sealed "in vacuum" in a special Pyrex glass ampoule with internal "break-off" tip.

[b] The purity has been evaluated from measurements of freezing points, as described in J. Research NBS **35**, 355 (1945) RP1676; unless otherwise indicated.

[c] Tolerance approximately ±10 percent.

[d] Estimated by analogy with isomers subjected to similar purification.

[e] When sealed. Polymer formed may be removed as residue by simple vaporization of the sample "in vacuum" at an appropriate temperature.

The price for these samples is $35 per unit, with the exception of No. 513-5S, which is $25 per unit. A complete list of NBS standard samples of hydrocarbons, together with instructions for ordering, may be obtained from the National Bureau of Standards, Washington 25, D. C.

Ionospheric Radio Propagation

The physical and mathematical theory underlying electromagnetic-wave propagation, with particular reference to radio-wave propagation by reflection from the ionosphere, is presented in NBS Circular 462, entitled *Ionospheric Radio Propagation*. At the same time these fundamental principles are brought into understandable relation with the practical problems of radio communication.

The variations of the ionosphere with locality, season, time of day or night, and solar activity, constitute a complex geophysical phenomenon, the principles of which must be understood in order to achieve the best use of radio. The nine chapters of this volume are planned to yield a basic understanding of this phenomenon and a satisfactory solution of the problems usually encountered in sky-wave communication. The mathematical theory underlying the propagation of radio waves by way of the ionosphere is first presented. Subsequent chapters deal with measurement techniques: structure and variations of the ionosphere; maximum usable frequencies; practical problems of ionospheric absorption; radio noise of atmospheric, solar, and cosmic origin; and lowest useful high frequencies. Problems are worked out in detail to assist the reader in applying the methods to specific cases.

NBS Circular 462, *Ionospheric Radio Propagation*, is available only from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at $1.00 a copy.

NBS Scientists

Dr. Robert D. Huntoon has been appointed Chief of the Atomic and Molecular Physics Division. He will also serve as consultant to several specialized laboratories of the Electronics Division. Dr. Huntoon joined the Bureau staff in 1941 and 4 years later was named Chief of the Electronics Section of the Ordnance Development Division, where he directed fundamental research on electronic circuits, control devices, and other electronic ordnance components. He has been Assistant Chief of the division, which he now heads, since its organization in 1947 as the Atomic Physics Division.

Dr. Allen V. Astin has been named Chief of the Electronics Division, to succeed the late **Harry Diamond.** Dr. Astin, who has served as Assistant Chief of the Electronics Division and prior to that in the same capacity with the Ordnance Development Division, has had wide experience in the fields of precision electrical measurements and liquid dielectrics, as well as electronics and electronic devices. Under his direction, the Electronics Division will proceed with its investigations and research on high-speed digital computers, electronic standards (including electron tubes and circuits), electronic ordnance, and guided missiles.

John H. Bower has retired as Assistant Chief of the Surface Chemistry Section after nearly 40 years of Government service. Mr. Bower has carried out extensive research on the properties and methods of analysis of waxes, polishes, soaps, and other detergents. He also has been active in the field of standards and specifications for these materials.

Nolan D. Mitchell has been designated Chief of the Fire Protection Section in the Building Technology Division. In this capacity he will direct NBS research on problems of fire protection and fire re-

sistance of building materials, especially as they relate to design and construction of buildings.

Howard S. Bean has been given added responsibilities as Chief of the newly formed Capacity, Density, and Fluid Meter Section of the Metrology Division. The new section was formed by consolidation of the Gas Measurement Section, of which Mr. Bean has been Chief, and the Capacity and Density Section. **E. L. Peffer,** former Chief of the latter group, died on July 2. Mr. Peffer had been a member of the Metrology Division staff for 35 years and had made numerous scientific contributions in this field. Among these are an invention that increased the speed of testing small pipettes, and publications giving data on density and expansivity of liquids.

NBS Publications

Periodicals [5]

Journal of Research of the National Bureau of Standards, volume **41**, number 3, September 1948. (RP1915 to RP1921, inclusive.)

Technical News Bulletin, volume **32**, number 9, September 1948. 10 cents.

CRPL–D49. Basic Radio Propagation Predictions for December 1948. Three months in advance. Issued September 1948. 10 cents.

Nonperiodical

Research Papers [5, 6]

RP1906. Strain test for evaluation of rubber compounds. Frank L. Roth and Robert D. Stiehler. 10 cents.

RP1907. Strain tester for rubber. William L. Holt, Ellis O. Knox, and Frank L. Roth. 10 cents.

RP1908. Barium aluminate hydrates. Elmer T. Carlson and Lansing S. Wells. 10 cents.

RP1909. Aliphatic halide-carbonyl condensations by means of sodium. Edgar A. Cadwallader, Abraham Fookson, Thomas W. Mears, and Frank L. Howard. 10 cents.

RP1910. Barium 2-ketolactobionate and the corresponding barium bromide double salt. William W. Walton and Horace S. Isbell. 10 cents.

RP1911. Infrared prism spectrometry from 24 to 40 microns. Earle K. Plyler. 10 cents.

RP1912. Mass spectra of octanes. Evelyn G. Bloom, Fred L. Mohler, Jonathan H. Lengel, and C. Edward Wise. 10 cents.

RP1913. Effects of substitute fuels on automotive engines. Clarence S. Bruce, Jesse T. Duck, and A. R. Pierce. 10 cents.

RP1914. Applications of magnetochemistry to polymers and polymerization. Pierce W. Selwood. 10 cents.

Building Materials and Structures Reports [5]

BMS112. Properties of some lightweight-aggregate concretes with and without an air-entraining admixture. Perry H. Petersen. 10 cents.

Circulars [5]

C462. Ionospheric radio propagation. $1.00.

Commercial Standards [5]

CS103–48. Rayon jacquard velour. (Second edition. Supersedes CS103–42.) 10 cents.

Miscellaneous [5]

M190. Standard time zones of the United States. (Supersedes M155.) 15 cents.

Simplified Practice Recommendations [5]

R194–48. Cotton jersey cloth and tubing for work gloves. (Supersedes R194–42.) 10 cents.

R202–48. Tank-mounted air compressors. (Supersedes R202–43.) 10 cents.

R231–48. Coffee grinds. 10 cents.

R232–48. Low-pressure lubricating devices. 10 cents.

Letter Circulars [7]

LC911. List of commercial standards, revised to July 1, 1948. (Supersedes LC890.)

LC912. Textiles: Sources of information.

LC913. Simplified practice recommendations. Alphabetical list, revised to September 1, 1948. (Supersedes LC895.)

LC914. Concrete masonry units.

Articles by Bureau Staff Members in Outside Publications [8]

Influence of boron on some properties of experimental and commercial steels. T. G. Digges and F. M. Reinhart. Steel Processing (108 Smithfield St., Pittsburgh 30, Pa.) **34**, 144 (March 1948).

Physical properties of electrodeposited chromium. A. Brenner, P. Burkhead and C. W. Jennings. Annual Proceedings American Electroplaters' Society (PO Box 168, Jenkintown, Pa.) p. 32 (1947).

Acabados que fijan los colorantes sobre los textiles haciendolos resistentes a diversas acciones. Carlos Camposortega. Camara Textil de Mexico (Mexico, D. F.) **11**, No. 11, 5 (July 30, 1948).

Modernos tipos de acabado en la industria textil Norteamericana. Carlos Camposortega. Camara Textil de Mexico **11**, No. 8, 12 (March 31, 1948).

Note on volume effect in coiling molecules. Robert Simha. J. Polymer Science (215 4th Ave., New York 3, N. Y.) **3**, 227 (1948).

On the distribution of water in cellulose and other materials. Robert Simha and John W. Rowen. J. Am. Chem. Soc. (1155 16th St. NW., Washington 6, D. C.) **70**, 1663 (1948).

Standardization of the optical densities of industrial eye-protective glasses. Ralph Stair. The Glass Industry (55 West 42d St., New York 18, N. Y.) **29**, 375 (July 1948).

A conductivity cell usable with viscous liquids, pastes, suspensions, and wetted solids. Earl Otto. Rev. Sci. Instruments (57 East 55th St., New York 22, N. Y.) **19**, 368 (May 1948).

Paper research and technology at the National Bureau of Standards. B. W. Scribner. The Paper Industry and Paper World (59 E. Van Buren St., Suite 1100, Chicago 5, Ill.) **30**, No. 3, 393; No. 4, 577 (June, July, 1948).

The role of a statistical consultant in a research organization. Churchill Eisenhart. Am. Statistician (1603 K St. NW., Washington 6, D. C.) **11**, 6 (April 1948).

Coefficients for expressing the first twenty-four powers in terms of Legendre polynomials. H. E. Salzer. Mathematical Tables and Other Aids to Computation (Brown Univ., Providence 12, R. I.), **3**, No. 21, 16 (1948).

The square root method for solving simultaneous linear equations. Jack Laderman. Mathematical Tables and Other Aids to Computation **3**, No. 21, 13 (1948).

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[5] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[6] Reprints from August Journal of Research.

[7] Letter Circulars are prepared to answer specific inquiries addressed to the National Bureau of Standards, and are sent only on request to persons having a definite need for the information. The Bureau cannot undertake to supply lists or complete sets of Letter Circulars or send copies automatically as issued.

[8] These publications are not available from the Government. Requests should be sent direct to the publishers.

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